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Updating Bulldozer Fireline Production Rates

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RESEARCH SUMMARY

Bulldozers are an effective but expensive machine for building fireline; therefore, it is important for firefighters to have some means of estimating the rates at which various dozers can build fireline in different kinds of cover and terrain. The handbooks and reports currently available are based on studies done in the 1950's and early 1960's, and the fireline construction rates offered are outdated. The models listed in the publications have been replaced by improved models or entirely new models with higher production rates.

The goal of this study was to develop production rates for bulldozers manufactured since 1975 and to revise the production rates for older dozers manufactured from 1965 to 1975. Because of budgetary limitations, it was not possible to duplicate past field studies. The authors therefore utilized production indexes that manufacturers had devised to indicate comparative earth-moving capabilities of various models. The indexes were used to adjust old production rates to fit more modern bulldozers. Results are displayed in tables and production curves by dozer size, fuels, and slopes. Changes in rates of fireline construction range from insignificant to 20 percent improvement, depending on site factors.

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INTRODUCTION

Since the early 1930's bulldozers have been used to construct firelines and perform other tasks in the control of wildland and prescribed fires (Pyne 1982). Dozers are especially valuable in situations where heavy vegetation, such as brush and logging slash, must be removed in order to establish a fireline to mineral soil. Although the use of bulldozers has been curtailed in some fragile ecosystems, the machines will continue to be a major tool in fireline construction.

Wildland fire managers need to know the rates of speed at which bulldozers can be expected to construct firelines in different situations of vegetation and slope. On a going fire, knowledge of bulldozer capabilities enables the fire boss and his assistants to determine the sizes and numbers of bulldozers needed to help produce the required length and width of fireline within a specified time. Planners need to know the production rates of bulldozers in order to meet the long-range objectives of fire management and land management. Planning models for the Forest Service's fire economics analysis (USDA Forest Service 1980) call for inputs of the production rates of different fireline-construction units, including bulldozers.

To facilitate short-term and long-range planning, fireline production rates for single bulldozers have been published in various fireline handbooks (British Columbia Forest Service 1976; USDA Forest Service 1971; National Wildfire Coordinating Group 1980). Because most of these rates are based upon studies made some 15 to 30 years ago, they primarily report the capabilities of older machines. They do not represent the capabilities of more recent models of bulldozers, which have been improved by new engines, transmissions, lubrication systems, hydraulic controls, and other features. The objective of this study, therefore, was to update the published rates of fireline construction for bulldozers manufactured since 1975. A secondary objective was to provide adjusted rates for bulldozers manufactured from 1965 to 1975; these rates are shown in appendix A. The study did not include production rates for tractor-drawn plows (Mobley and others 1979).

Past field studies of the fireline production rates of bulldozers were very costly and time-consuming (California Division of Forestry 1967; Steele 1961; USDA Forest Service 1948). Because of current budgetary limitations, however, land management agencies and protection agencies were unable to duplicate past field studies. Consequently, the authors sought a relatively inexpensive and yet reliable means of updating published production rates.

One such solution was found through correspondence with several manufacturers of bulldozers (Caterpillar Tractor Co.; International-Hough, Dresser Industries; John Deere Industrial Co.). One manufacturer had developed production indexes for each model of bulldozer built since 1947, based on general earthmoving capability. The production indexes seemed promising for adjusting fireline production rates established during two earlier, well-documented studies of bulldozer use for constructing firelines (California Division of Forestry 1967; Steele 1961).

This report describes how rates were updated and presents the new production rates in both tables and graphs. Although we believe that the adjusted rates are reasonably accurate, they must be validated in brief field tests.

SIZES OF BULLDOZERS USED IN FIRELINE CONSTRUCTION

In presenting rates of fireline production, it is desirable to classify bulldozers by size. Because there are no interagency standards, the authors have arbitrarily classified bulldozers into three general sizes:

Size class	Weight	Net horse power	Blade width	Track gage	Track area on ground
	Tons		*Ft*	*Ft*	*Inch^2*
Small	5-10	55-95	8-9	5±	1,500-2,900
Medium	11-20	100-195	10-12	6±	3,000-4,200
Large	21-40	200-350	13-16	7±	4,300-6,300

Because of the variation in the features of different makes of bulldozers, and because there are so many bulldozers in each size class, the specifications in the above table are broad and imprecise. The classes correspond to those of the National Interagency Incident Management System (NIIMS) as follows:

Study class	NIIMS class
Small	3
Medium	2
Large	1

Tables of detailed characteristics of specific makes and models of bulldozers, by size classes, are available from the authors. Also available from the authors is a partial inventory of bulldozers owned or controlled by State and Federal fire protection agencies in the United States as of early 1983. It includes information obtained from 23 States, all regions but one of the Forest Service, and four State divisions of the Bureau of Land Management.

PAST STUDIES OF BULLDOZER FIRELINE PRODUCTION RATES

There have been several studies of the rates at which bulldozers can build fireline. In 1969, Storey summarized bulldozer production rates that had been published in various fireline handbooks (Storey 1969). He found considerable variation in rates among the handbooks for the same size classes of bulldozers. Because original data were lacking and descriptions of conditions were poor, he was unable to explain the variation in terms of differences in vegetation, soil, slope, and other pertinent factors. His table summarizing the published rates showed differences because of bulldozer sizes and resistance-to-control classes for vegetation, but gave no breakdown of upslope and downslope rates. Storey concluded that most bulldozer fireline production rates being used at that time were suspect, inaccurate, limited in their usefulness, and badly outdated. He noted few exceptions to his general conclusions.

Forest Service Study

One of the earlier studies was made by the Forest Service's Arcadia Equipment Development Center (now San Dimas Equipment Development Center) in November and December 1946 (USDA Forest Service 1948). The primary objective of the study was to compare the performances of Caterpillar D6 and D7 bulldozers equipped with hydraulic angle dozers.

The principal concern was the rate of single-pass fireline construction in medium and heavy brush and on a variety of slopes. ("Single pass" is defined as a single bulldozer constructing a fireline to mineral soil, one-blade wide. The bulldozer may have to back up occasionally and veer to one side or the other to clear its blade of debris and earth.)

The study was conducted on the Angeles National Forest in southern California under conditions almost ideal for bulldozer operation. The ambient temperature, although not reported, was probably about 50° F (10° C) during the months of November and December. Soil that had been thoroughly moistened by fall rains provided maximum traction.

Among the results of the study were these:

1. The D6 compared favorably with the D7 for fireline construction in brush.
2. The D7 produced about 20 percent more length of single-pass fireline under all conditions of slope and vegetation.
3. Downslope production of fireline was greater than upslope production by an average of 115 percent at 20 percent slope, and 500 percent at 40 percent slope.
4. Maximum gradability with blade raised in light brush was about 73 percent for the D7 and 65 percent for the D6. In heavy brush the figures decreased to about 50 percent and 46 percent, respectively.
5. Angling the blade was always more effective in line construction than using a straight blade.

The fireline production rates of these tests are shown graphically in figure 1.

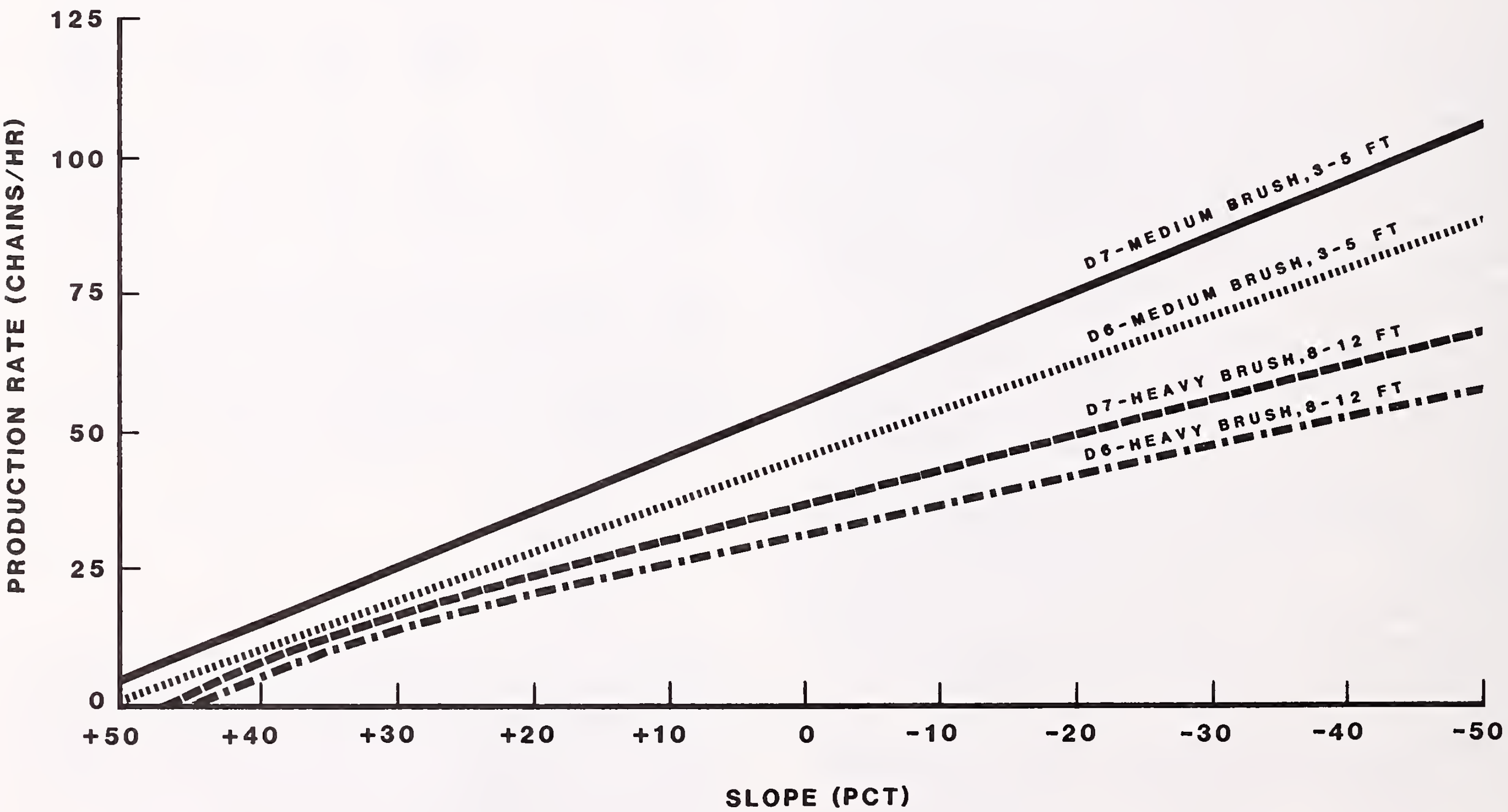

Figure 1.—Bulldozer fireline production rates (single pass) from 1946 study by Forest Service.

Robert W. Steele Study

During the period of 1954-59, Steele collected data on bulldozer fireline production rates during going fires and also on a few practice runs in timber types in Montana and Idaho (Steele 1961). Because most of the data came from actual wildfires, a wide range of makes and sizes of bulldozers was represented. Bulldozers observed in the study had cable-actuated blades that had to be manually changed from straight to angle position. All transmissions were manually shifted.

Steele classified his data using the following criteria:

a. Size of bulldozer (large, medium, small—using essentially the same size criteria as in this report).

b. Resistance to control of vegetation (extreme, high, medium, low).

c. Slope (to 30 percent upslope and 40 percent downslope).

d. Soil ("easy" and "rocky").

To account for operator skill, Steele included the work of only experienced, full-time operators.

Among the results of Steele's study were the following:

1. Vegetation affected production rates primarily in the amount and size of material that had to be cut or uprooted and in the rapidity with which it built up on the blade.

2. Slope was critical from the standpoint of being upslope or downslope; Steele found an optimum slope at minus 10 to 15 percent. Flatter slopes or upslopes produced slower rates, as did the steepest downslopes. On the latter Steele found that rates were reduced because of the increasing difficulty of backing bulldozers to clear blades of debris.

3. At 30 percent grade in vegetation with high resistance, Steele found that downslope rates were about 80 percent greater than upslope rates; for a 10 percent grade, the difference in production rates was about 33 percent.

4. Soil influenced production rates through differences in traction and through the need to move or to avoid large rocks.

The fireline production rates of Steele's study in "easy" soil are shown graphically in figures 2 through 4.

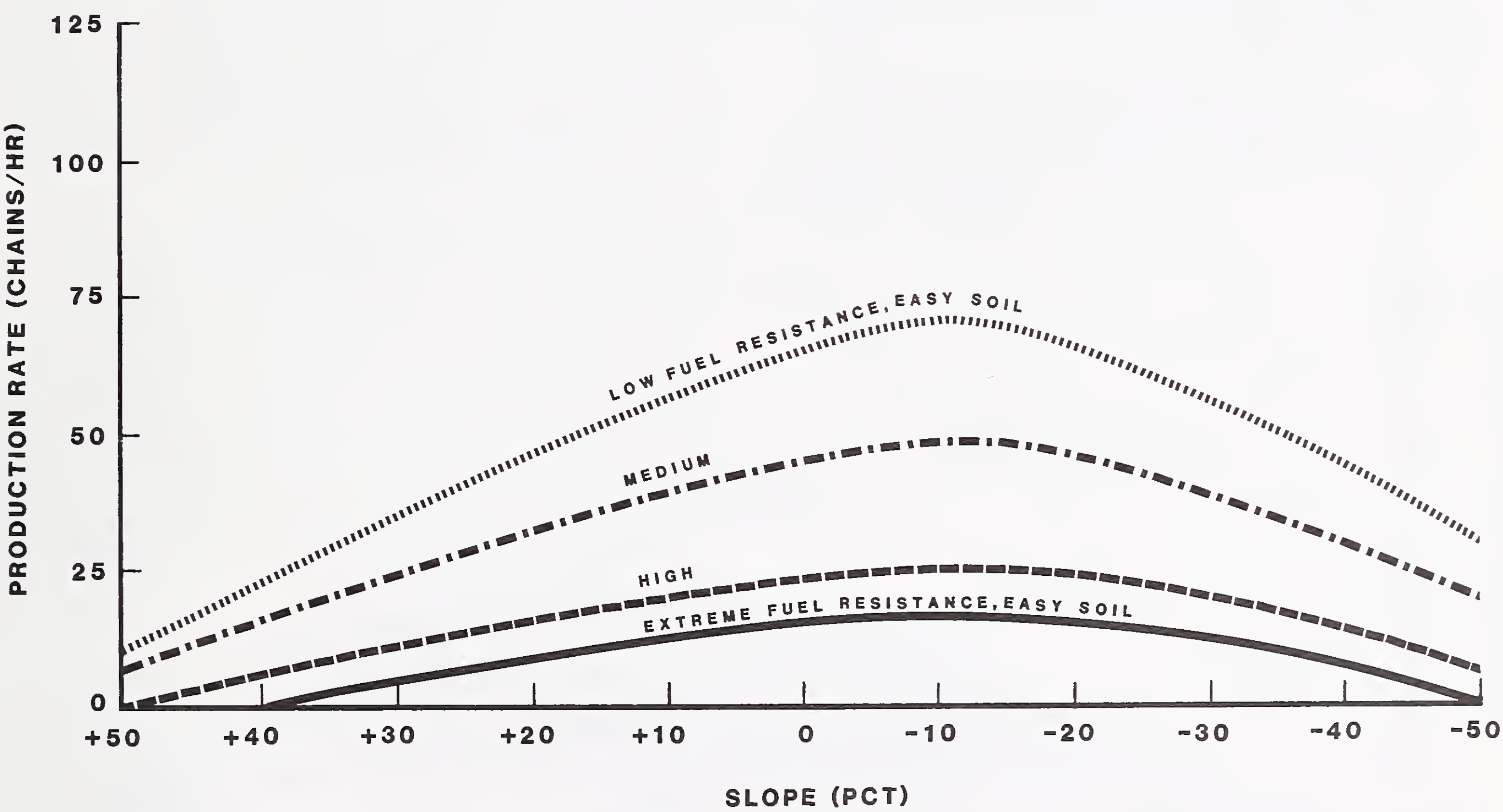

Figure 2.—Large bulldozer fireline production rates (single pass) from 1954-59 study by Robert W. Steele.

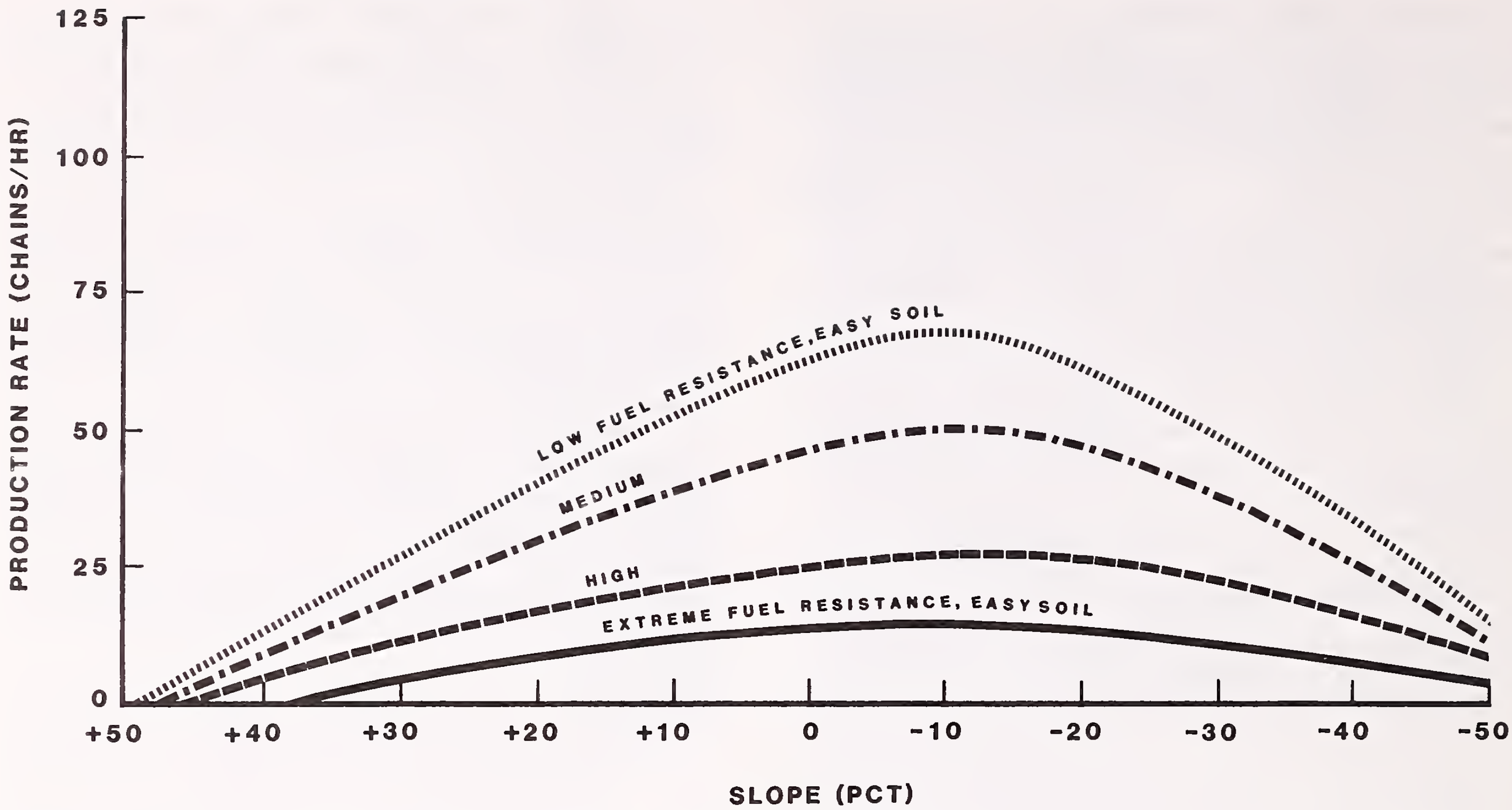

Figure 3.—Medium bulldozer fireline production rates (single pass) from 1954-59 study by Robert W. Steele.

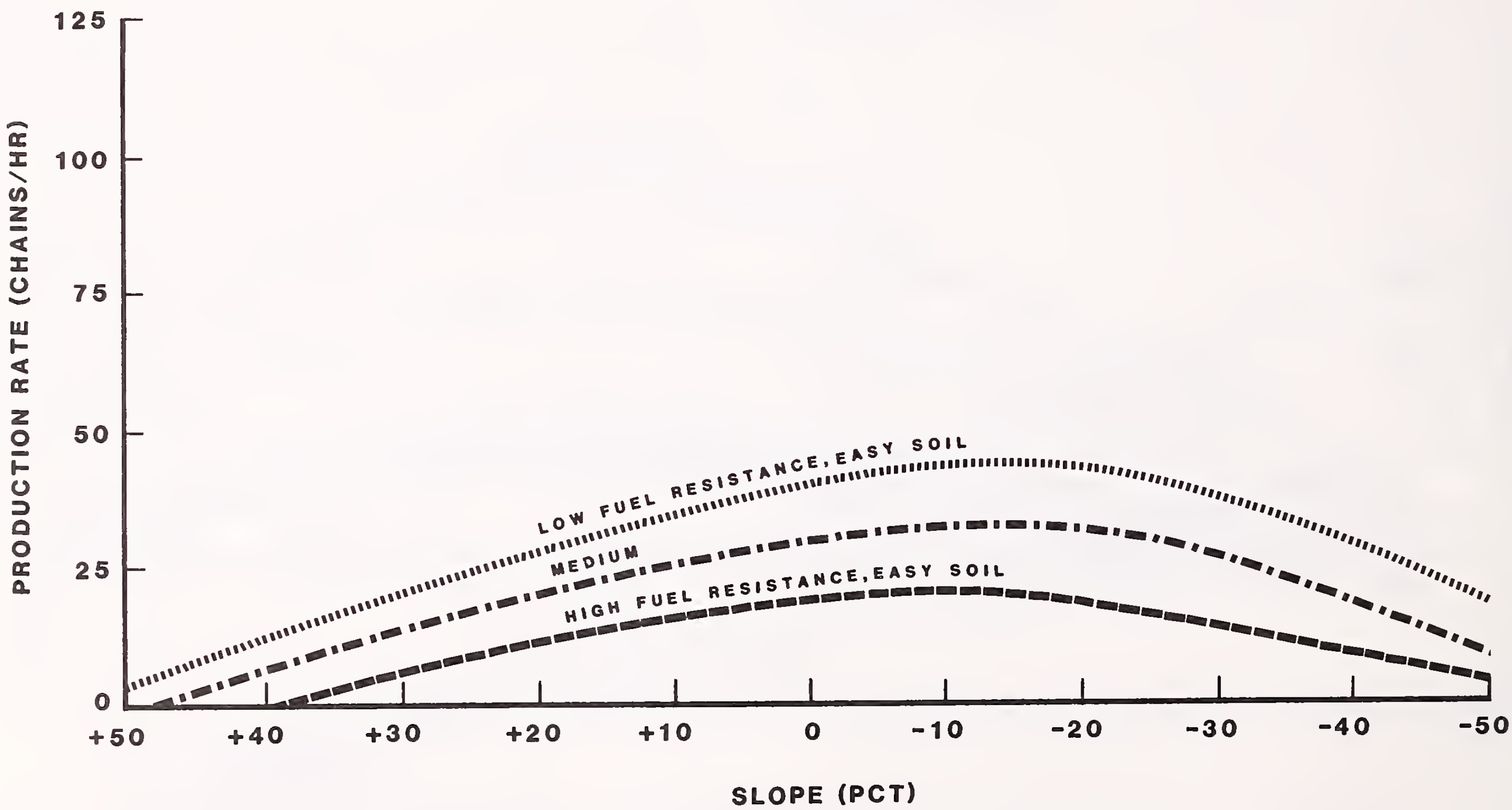

Figure 4.—Small bulldozer fireline production rates (single pass) from 1954-59 study by Robert W. Steele.

California Department of Forestry Studies

The California Department of Forestry (CDF) has conducted several studies of bulldozer fireline production rates: 1949 (medium-sized bulldozers), 1952 (small), 1955 (medium), 1956 (small), 1963 (medium), 1967 (small and medium), and 1975 (medium). The latter three studies used bulldozers with only power-shift transmissions and therefore began to account for the increased capabilities that came with more modern equipment.

The CDF's most extensive and carefully conducted study tested four makes of small bulldozers and three makes of medium bulldozers during a 5-week period in June and July 1967 (California Division of Forestry 1967). Ambient temperatures ranged from 78° to 106° F (26° - 41° C) in the afternoons, with most afternoons having temperatures in the mid- to high 90°'s. The high temperatures promoted overheating in two bulldozers, curtailing their use in the tests. The vegetation was mostly chaparral, with a few openings of grass. The chaparral was classed as low (up to about 3 feet [0.9 m] in height), medium (between 3 and about 8 feet [0.9 — 2.4 m]), and high (above 8 feet [2.4 m]). Line production was studied on slopes up to 50 percent, both upslope and downslope. Soil moisture, while not measured, was extremely low and representative of normal midsummer conditions in California. The surface soil was mostly shaley clay loam, from 3 to 24 inches (7.6 to 61 cm) thick and overlying a parent rock of fractured shale (personal correspondence, Hastings 1982). All bulldozers were fairly new and in good operating condition. Operators were selected from among the CDF's permanent employees, based upon their years of experience and demonstrated skills.

The study results included the following:

1. Downslope production of fireline was considerably greater than upslope; over all brush types, it averaged about 32 percent more at 10 percent slope, and about 140 percent at 30 percent slope.
2. While there was a gradual reduction in line production for steepening grades upslope, there was a gradual increase in line production for steepening grades downslope to the point where steepness caused the bulldozers to have difficulty in backing up for the purpose of clearing their blades and taking another run at cleaning the line.
3. Side slopes did not significantly affect upslope line production; downslope line production was reduced for medium-sized bulldozers for side slopes of 30 percent or more, but less so for the better balanced small-sized bulldozers.
4. Maximum gradability in light grass and favorable soil type averaged about 75 percent for medium bulldozers with raised blades in forward gear; maximum gradability was about 65 percent in reverse gear. The corresponding figures for small bulldozers averaged about 67 percent in forward gear and 56 percent in reverse.

The fireline production rates established in the 1967 study are shown in figures 5 and 6. The curves in these figures are averages from original data obtained for the four makes of small bulldozers and three makes of medium bulldozers.

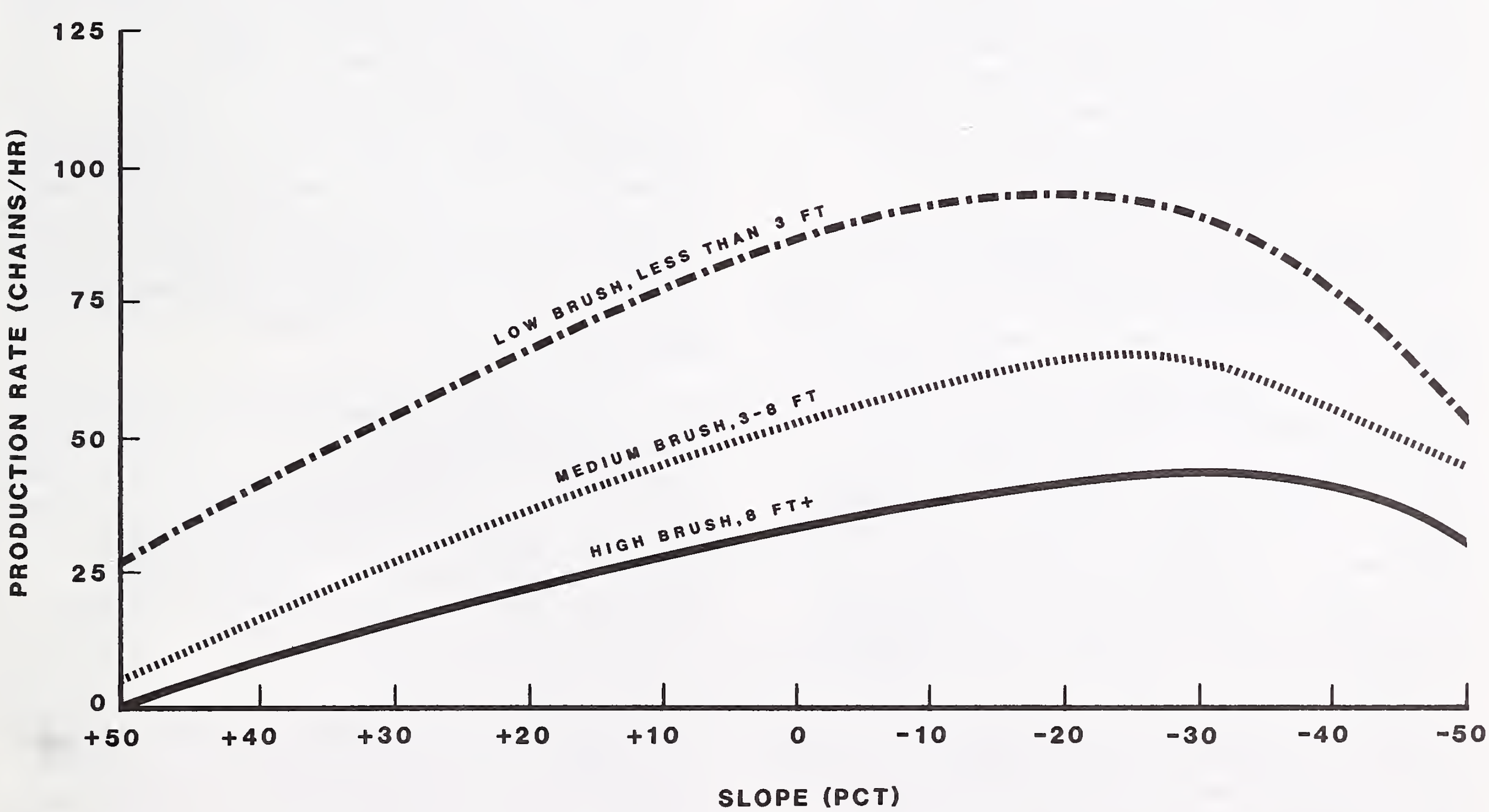

Figure 5.—Medium bulldozer fireline production rates (single pass) from 1967 study by California Department of Forestry.

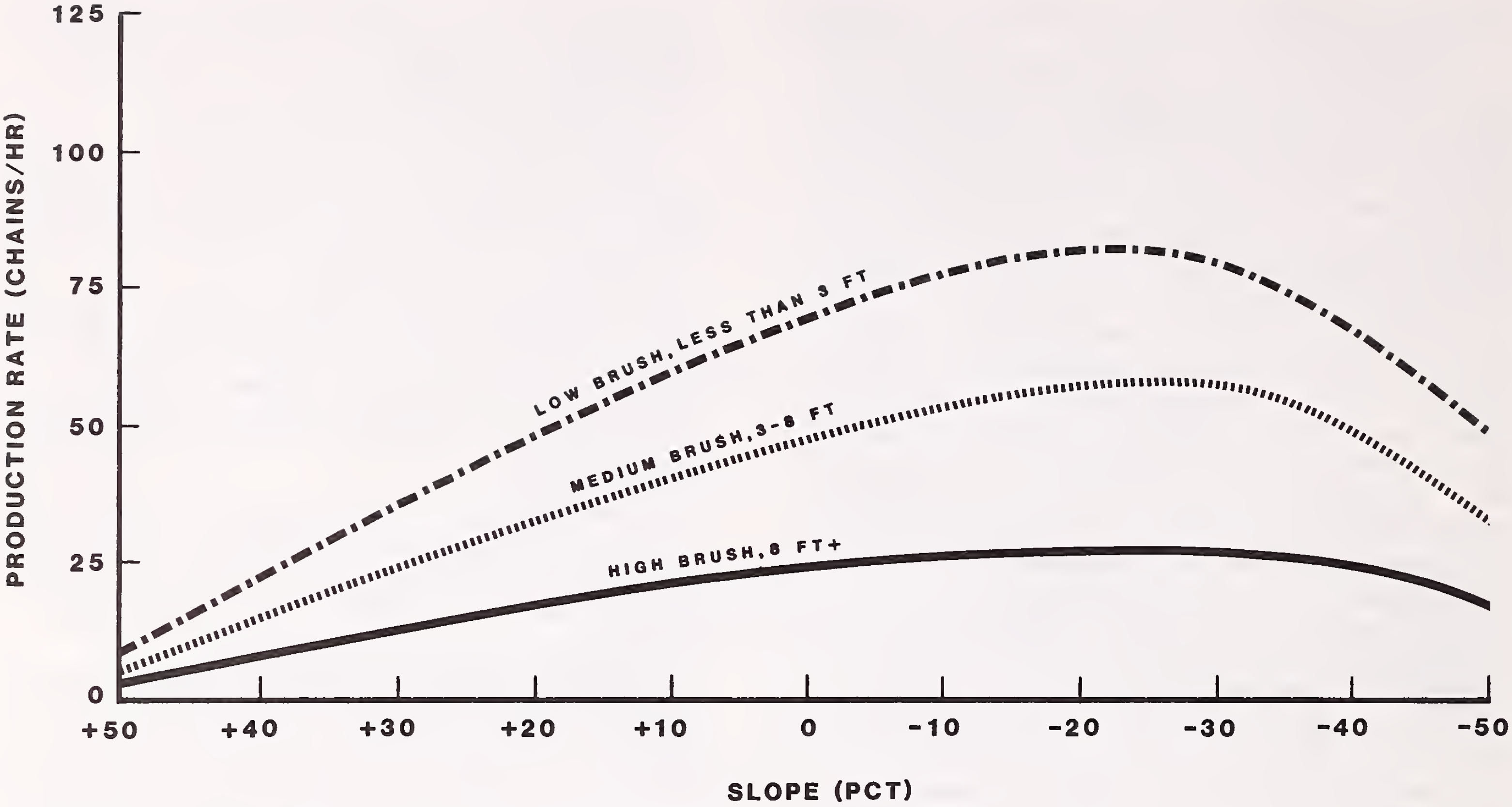

Figure 6.—Small bulldozer fireline production rates (single pass) from 1967 study by California Department of Forestry.

ANALYSIS OF PAST STUDIES

Unfortunately, original data for many past studies of bulldozer fireline production rates are lacking. Storey reported an inability to find such data for the production rates shown in various fireline handbooks and summarized in his report (Storey 1969). Even the rates in the most recent fireline handbook appear to be older ones that have been reworked on paper (National Wildfire Coordinating Group 1980).

To select a usable base of data for this study, therefore, there seemed to be no choice but to turn to those few published reports that presented observed production rates supported by well-documented methodology and environmental variables. Those reports were the three described above—the Forest Service's study of 1946, Steele's study of 1954-59, and the California Department of Forestry's study of 1967.

Because line production rates for bulldozers were displayed in different ways in each of the three reports, they had to be converted to a common graphic base for comparison in this report (figs. 1-6).

The results of the three published studies agreed in many respects, although there were some differences. The general agreements included the following important points:

1. The rate of upslope line production decreased gradually to the maximum working gradability of about 40 to 50 percent in heavy vegetation and to a slightly steeper grade in grass and other light vegetation.

2. The rate of downslope line production was considerably more than upslope for all grades of slope.

3. For Steele's and the CDF's studies, the rate of downslope line production increased to a grade of about 15 to 40 percent, depending on vegetation and soil, and then began to decrease because of the incremental difficulty of backing bulldozers to dump loads and make another forward run at cleaning the line.

4. The curves of line production in the Forest Service's 1946 study agreed closely with those of the CDF's 1967 study except for the tails of the downslope curves at 30 to 50 percent grade (figs. 7 and 8). This agreement existed despite the lapse of 21 years between the two studies and, consequently, despite an expected difference in bulldozer capability. The agreement in results, despite the time lapse, might be explained by the following reasons:

a. The November-December 1946 study was conducted under ideal conditions of thoroughly moistened soil and air temperatures that were typically low for the months; the June-July 1967 study was conducted under much more severe environmental conditions of dry soil and air temperatures ranging above 100° F (38° C).

b. The 1946 study was made with just two bulldozers from the same manufacturer; the curves shown for the 1967 study represented an average for several makes of bulldozers.

5. The maximum gradability for medium bulldozers was about the same in the Forest Service and CDF studies (about 70 percent). Steele did not specify maximum gradability in his study, although he used a slope of +30 percent as a "point of minimum speed" of upslope line production.

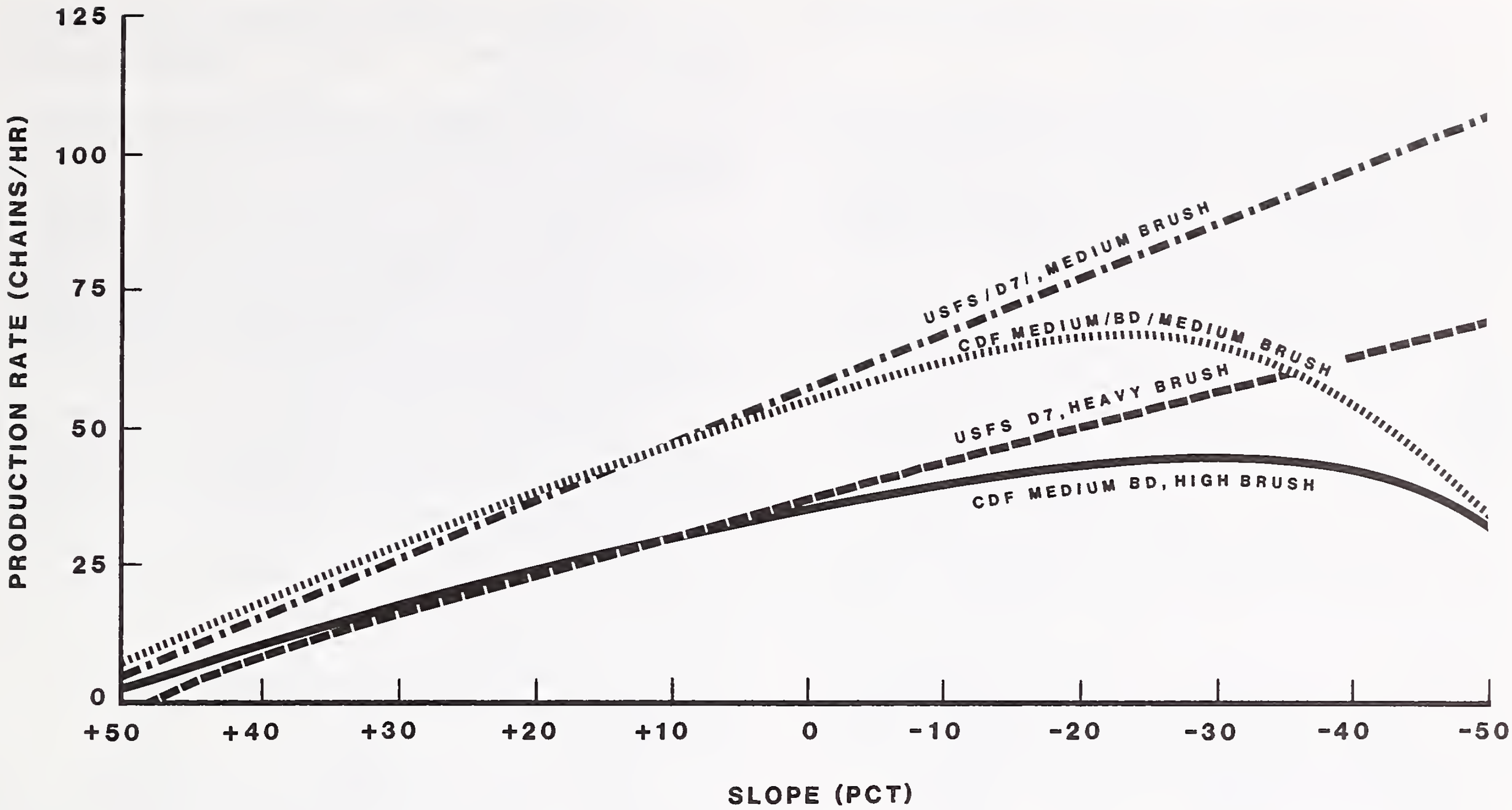

Figure 7.—Comparison of medium bulldozer fireline production rates from 1946 study by Forest Service and 1967 study by California Department of Forestry.

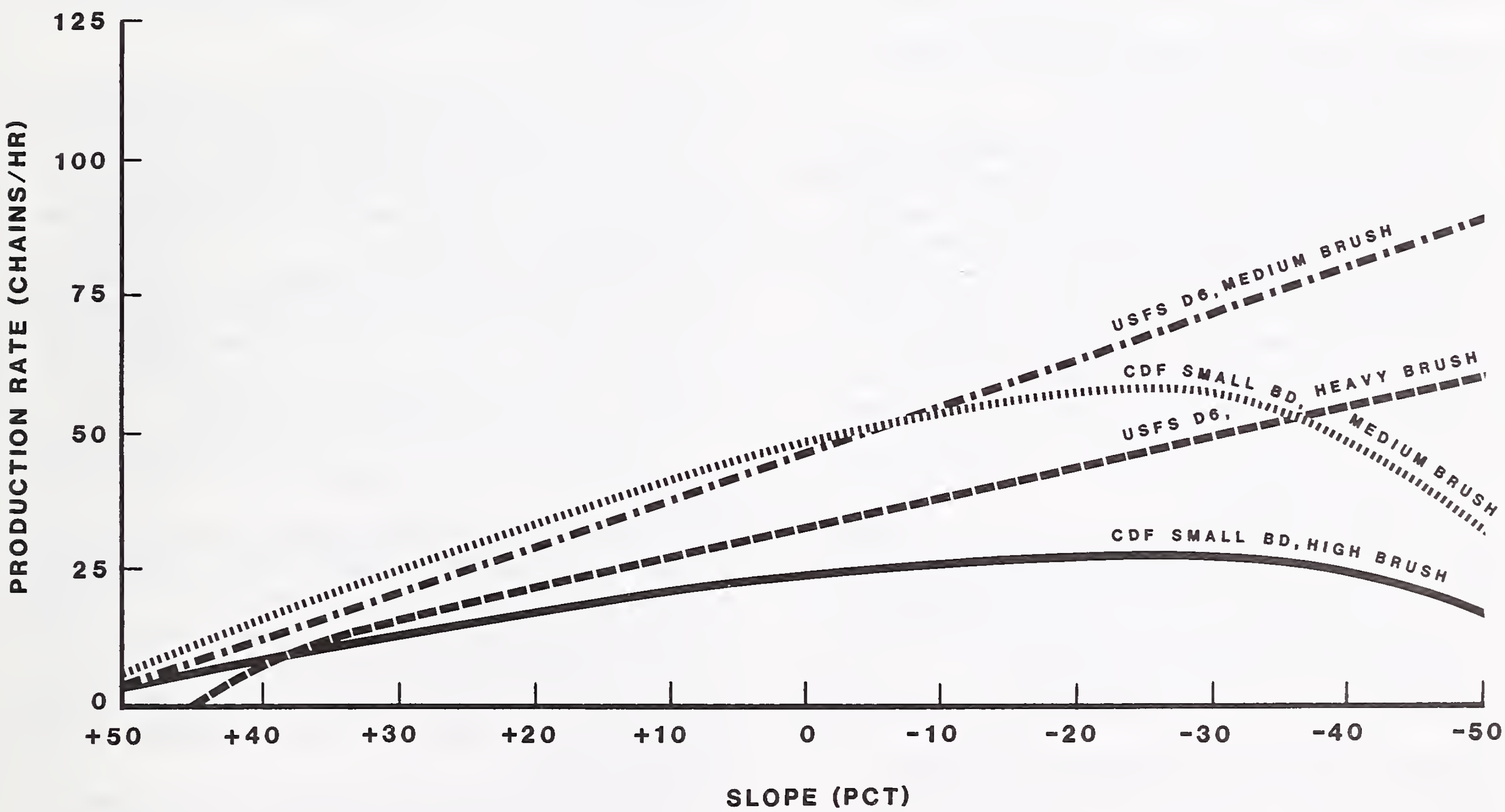

Figure 8.—Comparison of small bulldozer fireline production rates from 1946 study by Forest Service and 1967 study by California Department of Forestry.

Among the important differences in the results of the three studies were the following:

1. The Forest Service's production rates for downslopes continue to increase to a maximum workable grade of about 60 percent. Contrary to the results of Steele's and the CDF's studies, there was no decreasing tail in the production curve for the steeper slopes. The reason for the anomaly in the Forest Service's results could not be ascertained from the report.

2. The grade at which the maximum rate of line production occurred for downslopes was different for Steele's and the CDF's studies. For the former study, it occurred at 10 to 15 percent; for the latter, at 20 to 40 percent, depending on the size of bulldozer and the vegetative type. This difference might be attributed to the machines in Steele's study—older, less powerful models with manually operated transmissions and cable-activated blades. All in all, the older machines' lower capability also reduced the operators' confidence in their equipment.

3. Much of the vegetation in Steele's study was heavy timber or some variation (slash, downed logs, windfalls, closed stands of young growth, etc.). Vegetation in the Forest Service's and the CDF's studies was mostly chaparral, with some grass.

None of the three studies provided any significant data for two bulldozers working in tandem. Because no alternative sources of two-bulldozer rates of fireline production could be found, this study was confined to rates for single bulldozers constructing single-pass firelines.

SELECTION OF BASE RATES FOR FIRELINE PRODUCTION

Considering the available sources of bulldozer fireline production rates already discussed, it appeared that the base rates for this study should come from a combination of the CDF's 1967 study and Steele's study of 1954-59. Although the two studies had a few shortcomings, they did provide results that were realistic, defensible, usable, and feasible for updating. The Forest Service's 1946 study helped support the CDF's study, but could not be used because it was conducted under ideal postseason conditions and had an important and unexplained anomaly of no decrease in production rates for the steepest downslopes.

To be more useful in fire protection and fire management planning today, the production rates from the two selected studies had to be updated and rearranged. As a part of that updating process, separate rates needed to be established for the following variables:

1. Each of the 13 fire behavior fuel models (Anderson 1982).

2. Both upslope and downslope construction of fireline.

3. The first three slope classes of the National Fire-Danger Rating System (Deeming and others 1977): 0-25 percent, 26-40 percent, 41-55 percent.

4. Three size classes of bulldozers (small, medium, large).

Those four variables were the most important and practical to include in tables of bulldozer fireline production rates. Other conditions were held constant in this study and were generally consistent with Steele's and the CDF's studies:

a. Width of fireline. The rates are for single-pass lines: a single bulldozer constructing a fireline to mineral soil, one blade wide.

b. Line location. Assumed to be mostly indirect.

c. Operator qualifications. The best qualified based upon experience, knowledge, and demonstrated skill.

d. Equipment capability. Generally representative of bulldozers manufactured since 1975; in good maintenance and operating condition.

e. No lost time. Rates do not provide for rest stops, operator fatigue in extended attack situations beyond 6 to 8 hours, servicing of equipment, use of winches, or lost (unused) lines.

f. Fire conditions. Fire behavior assumed to be "average"; smoke does not obscure line construction.

g. Soil. Assumed to be fully dry and of a type that provides reasonably good traction.

h. Air temperature. Assumed to represent high summer temperatures ranging from 85° F (29° C) to 105° F (41° C).

i. Time of day. Assumed to be daylight hours.

If these constants differ from those in actual use, production rates shown in this study's tables and figures should be adjusted accordingly.

PROCEDURE FOR UPDATING BASE RATES

Current budgets for fire protection and fire management did not provide for extensive field studies for new models of bulldozers. Therefore adjusting the results of Steele's study of 1954-59 and the CDF's study of 1967 seemed to be the most practical alternative. That was done as follows:

1. Subjectively changing the shape of the curves from Steele's study to fit more closely the shape of the curves from the CDF's study.

2. Subjectively relating the various curves from the two studies to the 13 fire behavior fuel models.

3. Reading rates of line production from the curves for the midpoints of the three slope classes and tabulating them.

4. Adjusting the older production rates to account for the increased capability of newer models of bulldozers by using production indexes established by the manufacturers of bulldozers for other earth-moving applications.

5. Checking the logic and accuracy of the adjusted production rates by preparing new families of curves for each bulldozer size class, and making subjective changes where necessary.

6. Reading rates of line production from the new curves for the midpoints of the three slope classes and recording them in a new table; rearranging the updated fireline production rates in tables useful to planners of fire protection and fire management programs.

(A seventh step would be to verify the updated rates on a sample basis in an abbreviated field study some time in the future.)

Changing the Shape of Curves from Steele's Study

Because the older bulldozers observed in Steele's study had much less capability than newer machines, the production curves had to be adjusted upward at the two ends of maximum slope. A "zero" production rate at +30 percent or -40 percent slope, as shown in Steele's study, was not a reasonable base for calculating rates for newer bulldozers. Also, each curve for low fuel resistance needed to be raised to provide a more logical relationship within the overall family of curves. These adjustments were strictly subjective ("eyeballing") to make the curves from Steele's study resemble more closely those from the CDF's study of more modern bulldozers. The adjusted curves for Steele's study are shown with those of the CDF's study in figures 9 to 11.

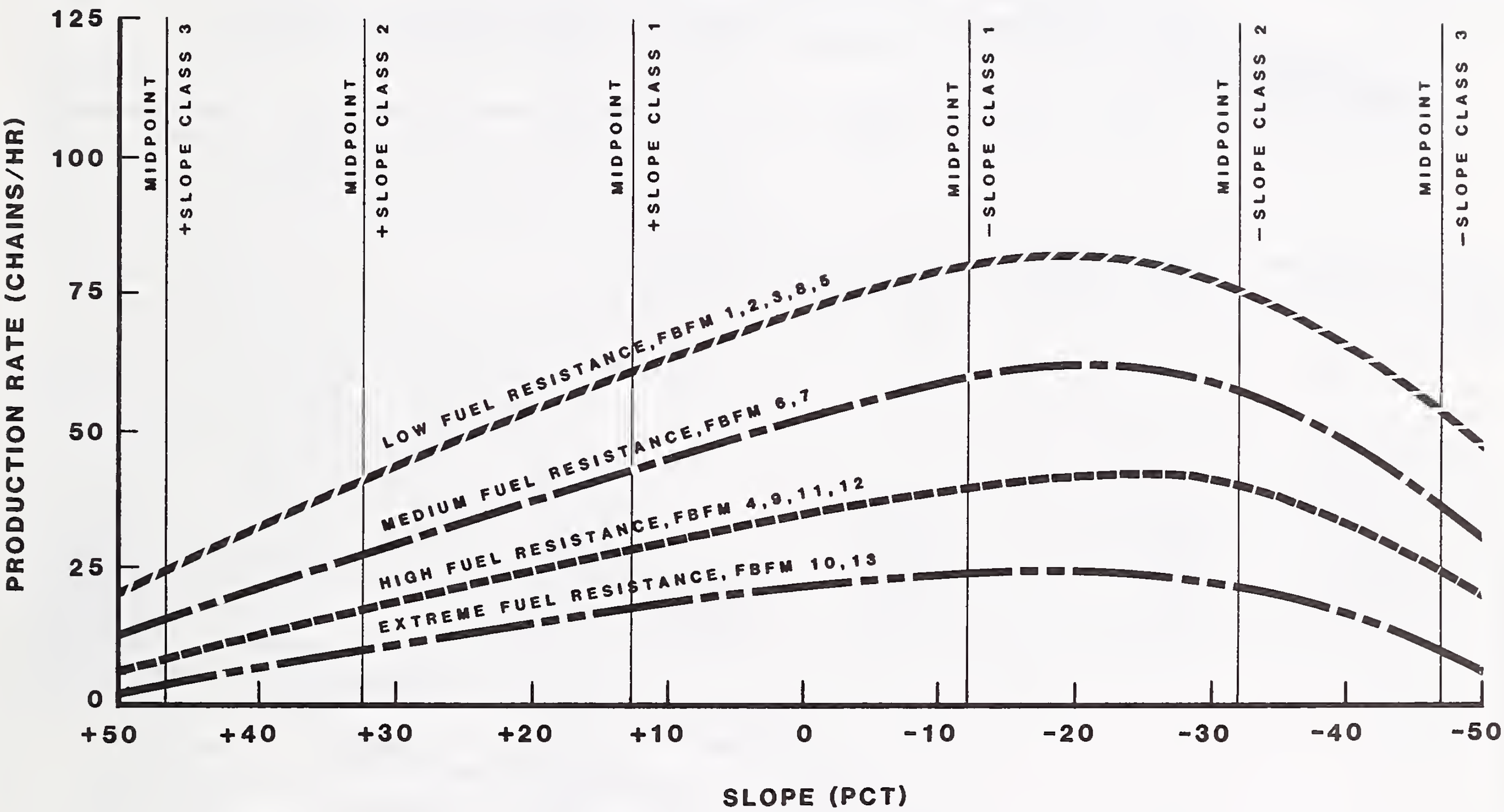

Figure 9.—Base rates for large bulldozer fireline production (single pass) from 1954-59 study by Robert W. Steele.

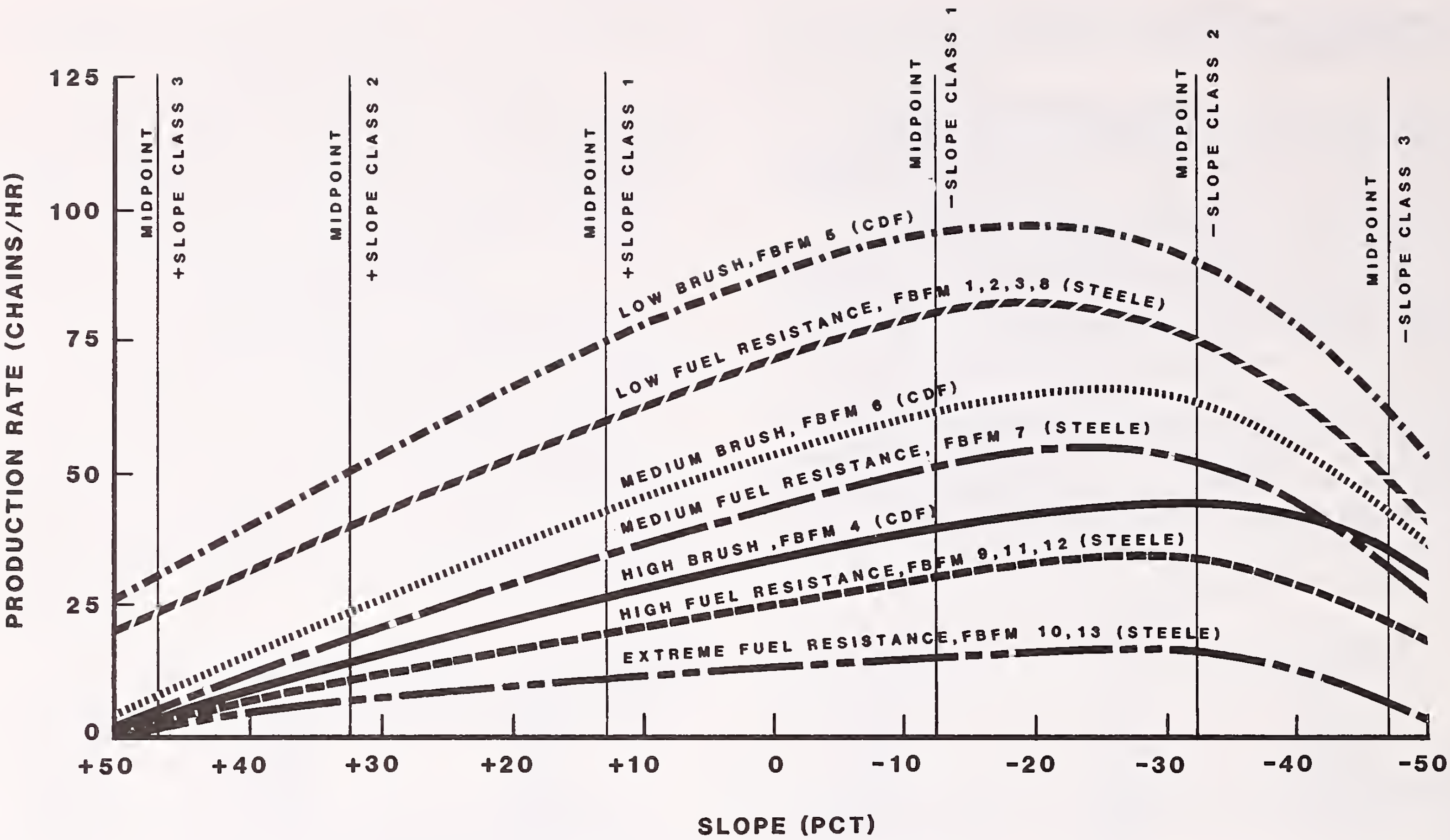

Figure 10.—Base rates for medium bulldozer fireline production (single pass) from 1954-59 study by Robert W. Steele, and 1967 study by California Department of Forestry.

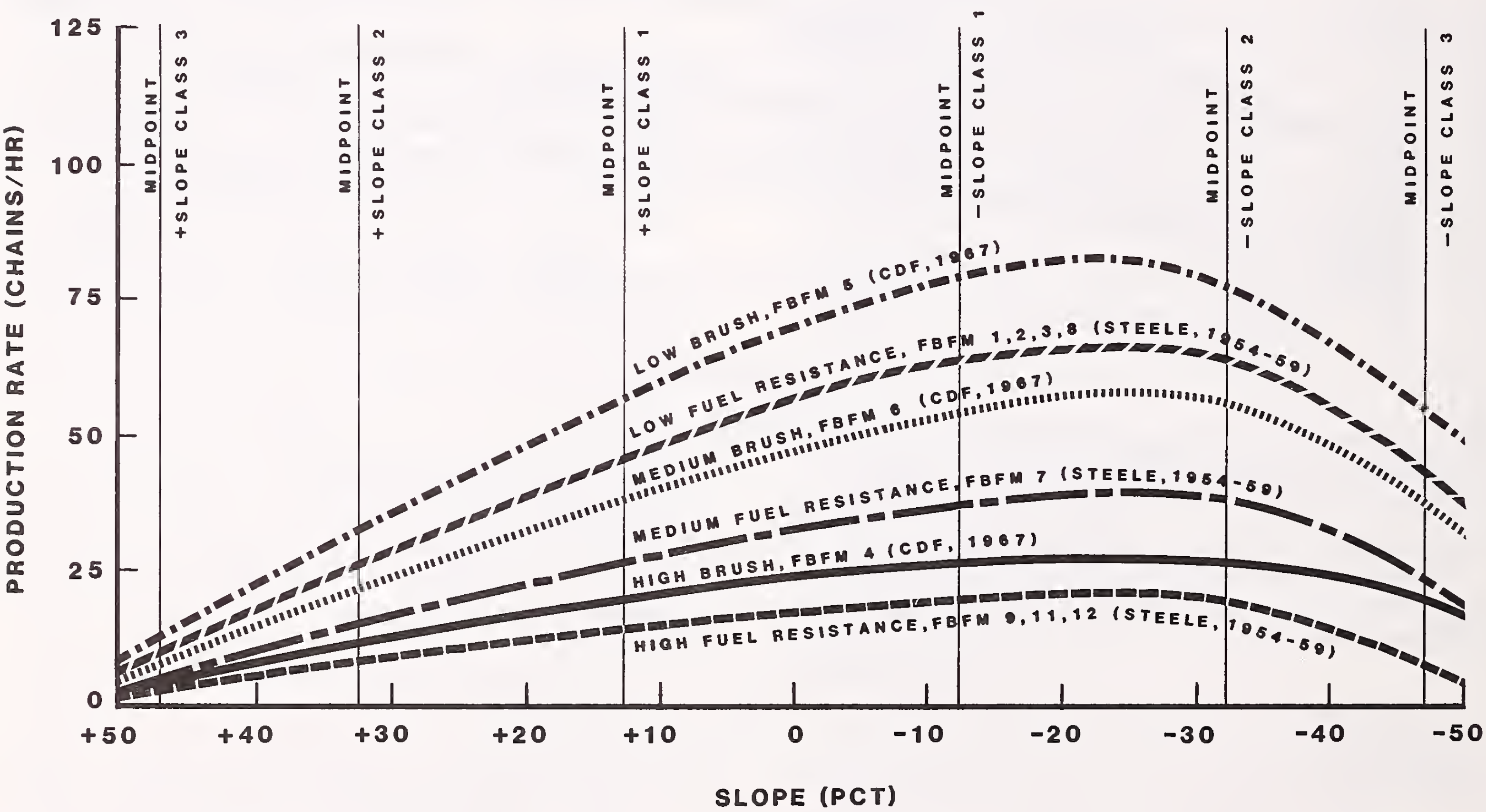

Figure 11.—Base rates for small bulldozer fireline production (single pass) from 1954-59 study by Robert W. Steele, and 1967 study by California Department of Forestry.

Relating the Curves to the 13 Fire Behavior Fuel Models

For fireline handbooks and tactical planning, it seemed most desirable to offer bulldozer fireline production rates for each of the 13 fire behavior fuel models. This breakdown would not fit some computerized models that utilize the fuel models of the National Fire-Danger Rating System (Deeming and others 1977). The 13 fire behavior fuel models have been correlated to the fuel models of the National Fire-Danger Rating System (Anderson 1982) and are presented in appendix B.

To establish production rates for the 13 fire behavior fuel models, it was necessary to compare descriptions of the fuel models to vegetation actually encountered and described in Steele's and the CDF's studies. That comparison was made possible by Anderson's (1982) publication, which described the 13 fire behavior fuel models in photographs and included a table of fuel volume by size classes.

Obviously, not all 13 fuel models were encountered in Steele's and the CDF's studies. Nevertheless, using the fuel model descriptions and the admonition to "regard vegetation as fire areas—as a fuel—and evaluate it in terms that relate to fire behavior" (Anderson 1974), it was possible to establish subjectively the tentative relationships shown in table 1. Admittedly, some of the tentative relationships may have to be changed, if indicated by future field testing.

In figure 11 note that there are no base rates for small bulldozers in fire behavior fuel models 10 and 13. Studies by Steele and the CDF indicated that small bulldozers are not effective in such heavy fuels and that production rates would be extremely low.

Tabulating Fireline Production Rates

The next step was to read the line production rates from figures 9 to 11 and record them in a table. Because the computerized planning models need fireline production rates for each slope class, the rates were read from the midpoints of those classes:

Slope class	Range of slope	Midpoint of class
	Percent	*Percent*
1	0-25	12.5
2	26-40	32.5
3	41-55	47.5

These rates were recorded in table 2 in the columns designated "Study."

With few exceptions, it is impractical to operate bulldozers on slopes beyond 55 percent (California Division of Forestry 1967). Steeper slopes can be effectively worked up to maximum gradability only if the vegetation is light and soil conditions are more favorable than those assumed for the tables of production rates in this study. If those conditions exist, then the rates shown in the tables can be adjusted appropriately.

Table 1.—Relationships between fire behavior fuel models and vegetation from the CDF's and Steele's studies

Fire behavior fuel model	General description	Curve from CDF's or Steele's study
1	Short grass	Steele—low fuel resistance
2	Grass understory in timber	Steele—low fuel resistance
3	Tall grass	Steele—low fuel resistance
4	Tall chaparral	CDF—high brush (for large bulldozers only, use Steele—high fuel resistance)
5	Short brush	CDF—low brush (for large bulldozers only, use Steele—low fuel resistance)
6	Dormant brush, hardwood slash	CDF—medium brush (for large bulldozers only, use Steele—medium fuel resistance)
7	Southern rough	Steele—medium fuel resistance
8	Litter in closed timber	Steele—low fuel resistance
9	Hardwood litter	Steele—high fuel resistance
10	Heavy litter in timber	Steele—extreme fuel resistance
11	Light logging slash	Steele—high fuel resistance
12	Medium logging slash	Steele—high fuel resistance
13	Heavy logging slash	Steele—extreme fuel resistance

Table 2.—Bulldozer fireline production rates obtained from past studies of bulldozers; adjusted to reflect capabilities of new models of bulldozers (rates shown are in chains-per-hour; taken from figures 9 to 11)

Vegetative type in study	Fire behavior fuel model	+ Slope class 1		+ Slope class 2		+ Slope class 3		- Slope class 1		- Slope class 2		- Slope class 3	
		Study	New	Study	New	Study	New	Study	New	Study	New	Study	New
Small bulldozers													
CDF 1967 study - Test PI = 13 (D4D-PS); new PI = 14 (D4E-PS); PIΔ% = 7.7													
Low brush	5	57	61	32	34	12	13	81	87	79	85	56	60
Medium brush	6	38	41	22	24	7	8	55	59	58	62	39	42
High brush	4	20	22	11	12	3	3	27	29	28	30	20	22
Steele 1954-59 study - Test PI = 10 (D4-DD); new PI = 14 (D4E-PS); PIΔ% = 40.0													
Low fuel resistance	1,2,3,8	46	64	26	36	10	14	64	90	66	92	44	62
Medium fuel resistance	7	26	36	15	21	5	7	37	52	40	56	25	35
High fuel resistance	9,11,12	14	20	8	11	2	3	21	29	21	29	8	11
Medium bulldozers													
CDF 1967 study - Test PI = 18 (D6C-PS); new PI = 21 (D6D-PS); PIΔ% = 16.7													
Low brush	5	76	87	51	60	31	36	97	113	93	109	63	74
Medium brush	6	43	50	23	27	8	9	62	72	65	76	43	50
High brush	4	27	32	14	16	3	4	40	47	46	54	37	43
Steele 1954-59 study - Test PI = 14 (D6-DD); new PI = 21 (D6D-PS); PIΔ% = 50.0													
Low fuel resistance	1,2,3,8	60	90	40	60	24	36	82	123	78	117	50	75
Medium fuel resistance	7	34	51	18	27	5	8	52	78	55	83	33	50
High fuel resistance	9,11,12	19	29	10	15	3	5	31	47	36	54	22	33
Extreme fuel resistance	10,13	11	17	7	11	2	3	15	23	17	26	7	11
Large bulldozers													
Steele 1954-59 study - Test PI = 19 (D7D-DD); new PI = 28 (D7G-PS); PIΔ% = 47.4													
Low fuel resistance	1,2,3,5,8	62	91	42	62	24	35	84	124	80	118	56	83
Medium fuel resistance	6,7	43	63	28	41	15	22	62	91	61	90	39	57
High fuel resistance	4,9,11,12	29	43	18	27	8	12	41	60	42	62	27	40
Extreme fuel resistance	10,13	18	27	10	15	3	4	26	38	23	34	11	16

Notes:
"Study" rates of bulldozer production are taken from past studies indicated in the left column.
"New" rates of bulldozer production are the "study" rates adjusted by "Δ%".
"PI" = Production Index from table 3 for the appropriate size of bulldozer used in past studies and for new models of bulldozers.

Updating Fireline Production Rates

The fireline production rates established from the curves in figures 9 to 11 needed to be increased to account for the improved capability of newer models of bulldozers. This was done with data provided by three manufacturers of bulldozers. Although the data were derived from earth-moving tests other than building fireline, the authors assumed that it could be extrapolated to fireline construction.

The Caterpillar Tractor Co. supplied a table of productivity indexes for its bulldozers manufactured since 1947 (table 3). A letter from that company stated:

> The productivity indices shown are based on extensive studies in conventional dozing applications over the past thirty years. They should provide a realistic estimate of productivity increases in fire trail construction. Note, for example, today's D6D powershift is more productive than the popular 17A series D7 of 1955-1961. (Caterpillar Tractor Co. 1982)

As further examples, table 3 shows a production index (PI) of 14 for Caterpillar's new D4E-PS (in the small size class of bulldozers) in comparison to a PI=13 for the D4D-PS used in CDF's 1967 study. That represents an expected increase in productivity of 7.7 percent (14-13/13 = 0.077). Similarly, Caterpillar's D6D-PS (in the medium size class of bulldozers) has a PI=21, compared to a PI=18 for the D6C-PS used in CDF's 1967 study. This is an expected increase in productivity of 16.7 percent (21-18/18 = 0.167).

Table 3.—Productivity indexes for Caterpillar tractors

Model	Serial number	Years manufactured	Productivity index
D2-DD	4U	47-58	7
D3-PS	79U	72-79	11
D3B-PS	27Y	79-	12
D4-DD	6U	47-59	10
D4C-DD	39A	59-63	11
D4D-DD	78A	63-68	13
D4D-DD	82J	68-73	13
D4D-PS	83J	68-73	14
D4D-PS	22C	67-68	13
D4E-DD	27X	73-	13
D4E-PS	28X	73-	14
D5-DD	82H	67-73	16
D5-PS	84H	67-73	17
D5B-DD	23X	73-	17
D5B-PS	25X	73-	18
D6-DD	9U	47-59	14
D6B-DD	44A	59-67	15
D6C-DD	74A	63-67	17
D6C-PS	76A	63-67	18
D6C-DD	99J	67-75	19
D6C-PS	10K	67-75	20
D6D-DD	4X	75-	20
D6D-PS	4X	75-	21
D7-DD	3T	47-55	17
D7C-DD	17A	55-59	19
D7D-DD	17A	59-61	20
D7E-DD	47A	61-66	21
D7E-PS	48A	61-66	22
D7E-DD	47A	66-69	24
D7F-DD	93N	69-75	24
D7E-PS	48A	66-69	25
D7F-PS	94N	69-75	25
D7G-DD	91V	75-	26
D7G-PS	92X	75-	28
D8-DD	2U	46-53	21
D8-DD	13A	53-55	23
D8F-DD	14A	55-58	24
D8G-TC	15A	55-58	25
D8H-DD	36A	58-66	30
D8H-TC	35A	58-61	32
D8A-PS	46A	58-66	34
D8H-DD	36A	66-75	37
D8H-PS	46A	66-75	39
D8K-DD	76V	75-82	40
D8K-PS	77V	75-82	42
D8L-PS	53Y	82-	52

DD = Direct drive tranmission with clutch.
TC = Direct drive with torque converter.
PS = Power shift transmission.

These productivity indexes were supported by information from International-Hough, Dresser Industries and John Deere Industrial Equipment Co. International presented data that showed its new TD8E (in the small size class of bulldozers) to be 3 to 5 percent more productive in road construction than its TD9B, used in CDF's 1967 study (International-Hough, Dresser Industries 1982). Also, its new TD15C (in the medium size class of bulldozers) was said to be 21 percent more productive than its TD15B, used in CDF's study. These percentage increases agreed well with Caterpillar's figures for the two size classes of bulldozers.

John Deere presented evidence that its new 750 and 850 models (in the medium size class of bulldozers) were about 12 to 15 percent more efficient than medium bulldozers used in CDF's 1967 study (John Deere Industrial Equipment Co. 1982). Again, that increase agreed well with Caterpillar's figures for medium bulldozers.

Because of the independence of the studies made by the three manufacturers and the acceptably close agreement of their data, this study used that data for updating production rates from the CDF's and Steele's studies. The updated rates are shown in table 2 in the columns designated "New."

The production indexes (PI) used in table 2 were derived as follows:

Small bulldozers

CDF's 1967 study

Caterpillar D4D-PS (Ser. No. prefix 22C), used in study	PI = 13
Caterpillar D4E-PS (Ser. No. prefix 28X), new model	PI = 14
Change in PI (14-13/13)	PIΔ% = 7.7

Steele's 1954-59 study

Caterpillar D4-DD (Ser. No. prefix 6U), used in study	PI = 10
Caterpillar D4E-PS (Ser. No. prefix 28X), new model	PI = 14
Change in PI (14-10/10)	PIΔ% = 40.0

Medium bulldozers

CDF's 1967 study

Caterpillar D6C-PS (Ser. No. prefix 76A), used in study	PI = 18
Caterpillar D6D-PS (Ser. No. prefix 4X), new model	PI = 21
Change in PI (21-18/18)	PIΔ% = 16.7

Steele's 1954-59 study

Caterpillar D6-DD (Ser. No. prefix 9U), used in study	PI = 14
Caterpillar D6D-PS (Ser. No. prefix 4X), new model	PI = 21
Change in PI (21-14/14)	PIΔ% = 50.0

Large bulldozers

Steele's 1954-59 study

Caterpillar D7C-DD (Ser. No. prefix 3T), used in study	PI = 19
Caterpillar D7G-PS (Ser. No. prefix 92X), new model	PI = 28
Change in PI (28-19/19)	PIΔ% = 47.4

Preparing New Curves of Adjusted Production Rates

The adjusted production rates in table 2 appeared to be reasonable and ready for use by fire management planners. Because the adjusted rates came from two separate studies and were based on different sets of adjustment factors, it seemed prudent to reexamine them. New curves were drawn for each fuel model using the "new" rates from table 2.

The curves for some fuel models were very close in several instances for medium and small bulldozers.

(Although these curves are not showing, the "new" rates in table 2 reveal the close relationships.) Consequently, the curves for fuel models 1, 2, 3, and 8 were combined with that of fuel model 5 by simple averaging. The same procedure was used to combine the curves of fuel models 6 and 7, and that of fuel model 4 with the one for fuel models 9, 11, and 12. These combinations, shown in figures 12 to 14, all appeared reasonable for two reasons:

1. The rates in table 2 were close in each combination.
2. Considering all aspects of their descriptions (Anderson 1982), the fuel models within each combination appeared to offer about the same resistance to fireline construction by bulldozers.

Future verifying tests in field operations should reveal whether or not the combinations are real and satisfactory.

The only major variance was in slope class 3, downslope, in the combination of fuel model 4 with fuel models 9, 11, and 12 (table 2). The difference came from the CDF's original field data for fuel model 4. The data caused the production curves for both medium and small bulldozers to fall off very gradually at slope class 3, downslope, an anomaly in comparison with the other CDF curves. (See curve for "high brush" in figures 10 and 11.) Checking that anomaly with the CDF personnel who conducted the 1967 test revealed that despite and because of the meager data, the **gradual** fall-off of production rates was not real. More real was the **sharp** fall-off shown in figures 12 to 14. The sharp fall-off reflects the decreasing capability of bulldozers to back up and empty their blades on downslopes of more than 40 percent.

Rearranging Bulldozer Fireline Production Rates

Updated production rates from figures 12 to 14 were then arranged into a usable format in table 4. This format might be appropriate for future editions of fireline handbooks.

Appendix A includes a table of suggested fireline production rates for bulldozers manufactured from 1965 to 1975 (table 5), which should be useful for two reasons:

1. Fire protection agencies indicated that many bulldozers manufactured during that period will continue to be used for several years.
2. Rates for these bulldozers published in current fireline handbooks appeared inaccurate and incomplete.

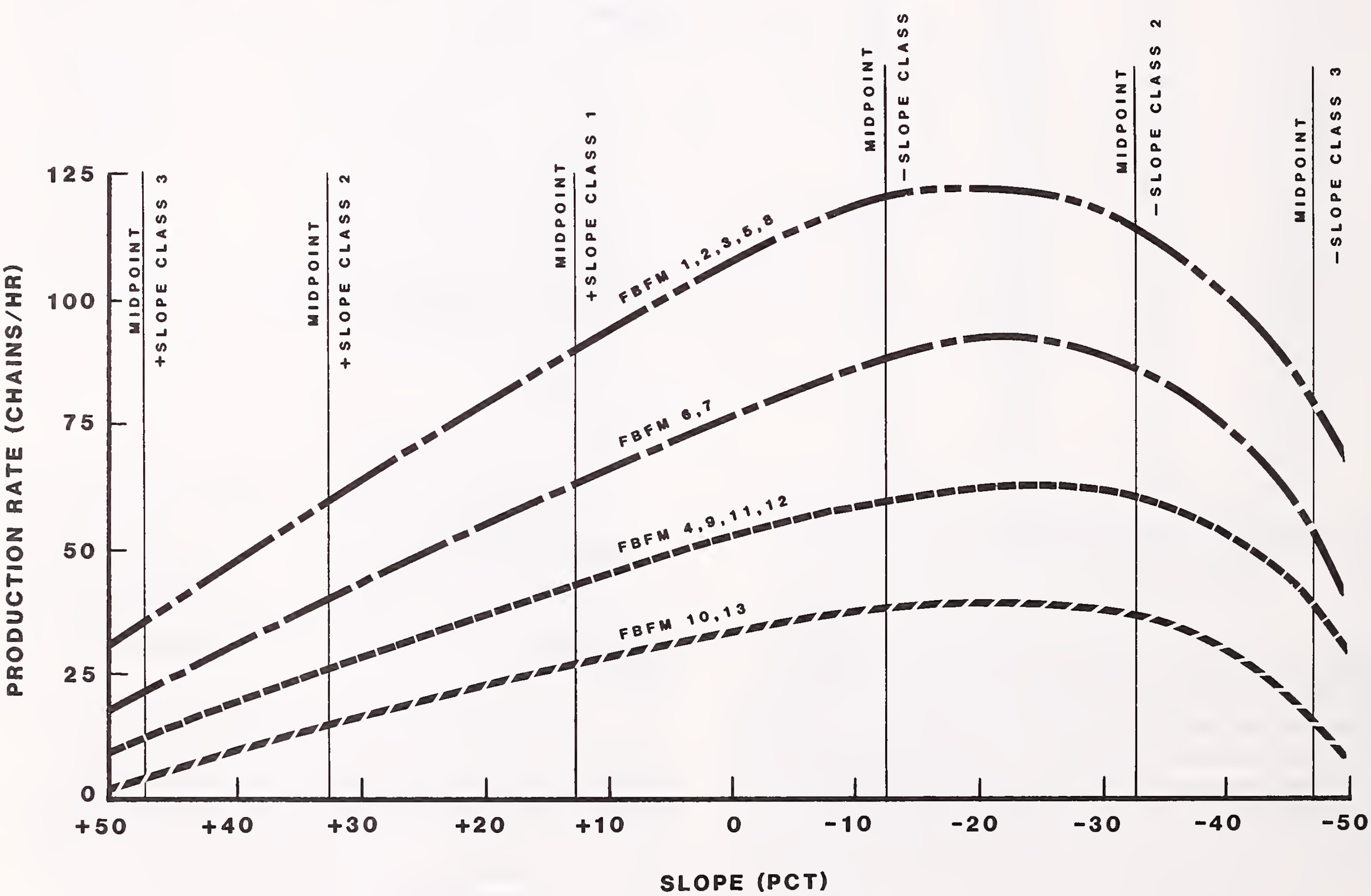

Figure 12.—Base rates for large bulldozer fireline production (single pass) adjusted to fit bulldozers manufactured since 1975.

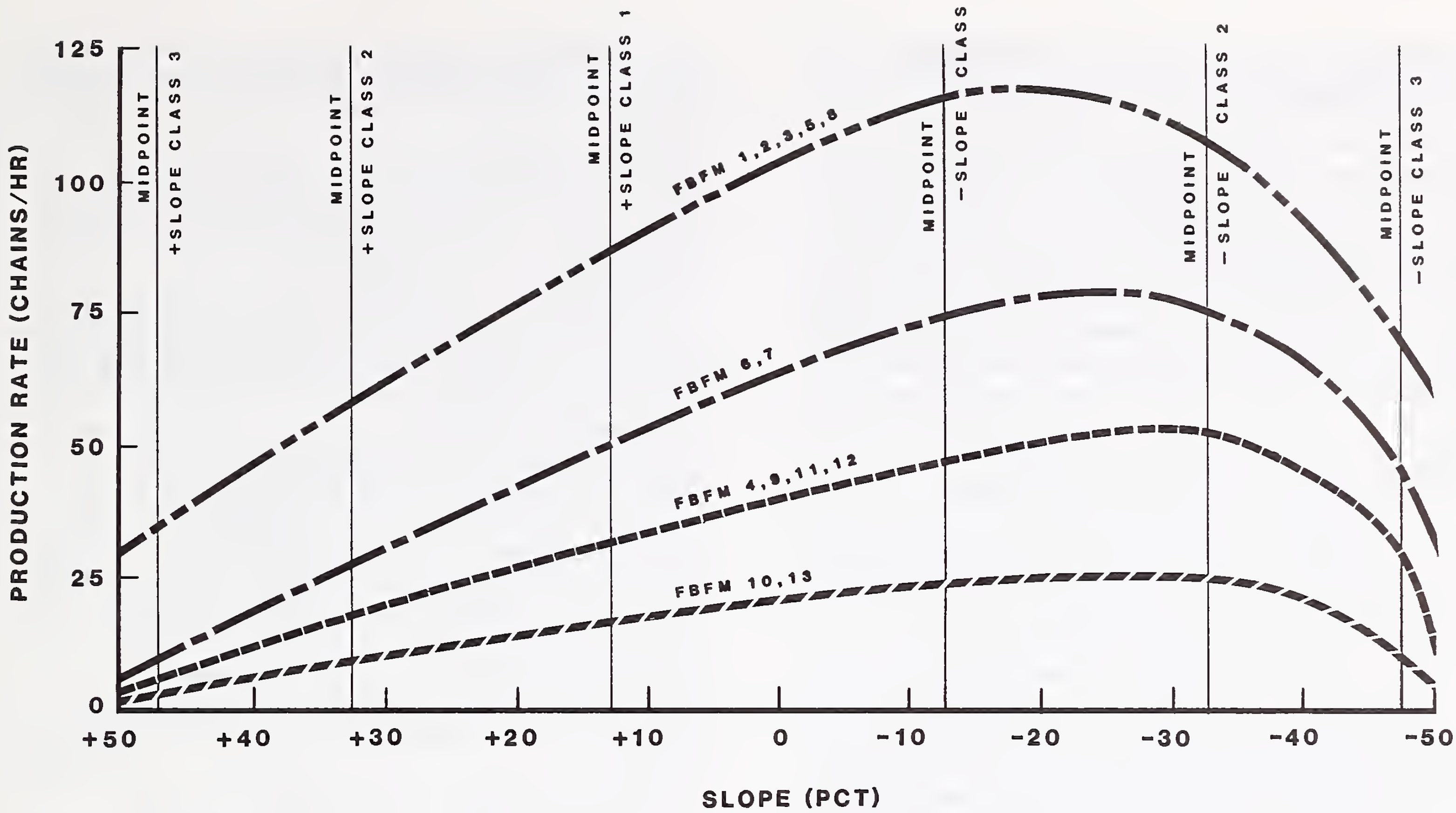

Figure 13.—Base rates for medium bulldozer fireline production (single pass) adjusted to fit bulldozers manufactured since 1975.

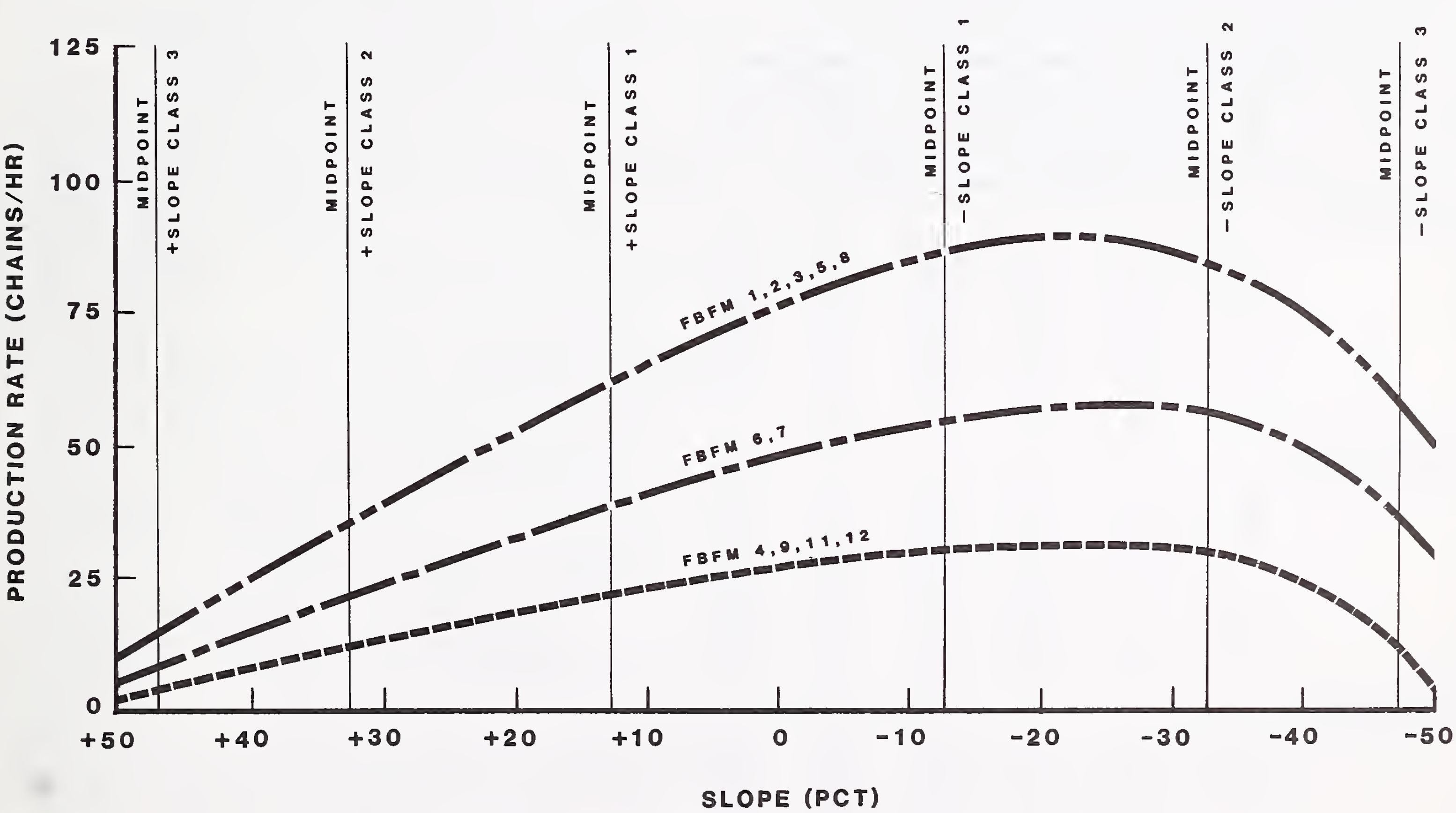

Figure 14.—Base rates for small bulldozer fireline production (single pass) adjusted to fit bulldozers manufactured since 1975.

Verifying Updated Rates of Fireline Production

The rates in table 4 (and in table 5 in appendix A) are "paper rates," derived in the manner described in this report. There remains the task, therefore, of verifying those rates. Because of limited funds, extensive field tests are not possible. Instead, a limited number of constructed firelines will be measured in abbreviated field tests that have yet to be planned and conducted. In the meantime, the revised bulldozer production rates in tables 4 and 5 are available for use in operational situations.

DISCUSSION AND SUMMARY

The purpose of this study was to provide fireline production rates for modern bulldozers. To accomplish that task, the following steps were taken:

1. Bulldozers were arbitrarily classed as small, medium, or large according to certain criteria.
2. Past studies were sought that presented production rates for bulldozers and described how the rates were obtained. Three such studies were found. Two of them, one by Robert W. Steele in 1954-59 and another by the California Department of Forestry (CDF) in 1967, were chosen to provide base rates for this study (figs. 2-6).
3. The production curves from Steele's older study were subjectively changed by a small amount to match the capabilities of the more modern bulldozers used in the CDF's tests (figs. 9-11).
4. The production curves in figures 9 to 11 were related subjectively to the 13 fire behavior fuel models based upon descriptions of vegetation encountered in Steele's and the CDF's studies (table 1).
5. The production curves from the two base studies were used to tabulate fireline production rates according to bulldozer size, the 13 fire behavior fuel models, and the first three slope classes of the National Fire-Danger Rating System (table 2).
6. The fireline production rates from the two base studies were updated by multiplying them by factors related to "production indexes" developed for various models of bulldozers. The "production indexes" were obtained from bulldozer manufacturers who had developed them for other earth-moving applications (table 3). The updated rates were added to table 2.
7. The updated rates in table 2 were used to prepare new curves of fireline production rates (figs. 12-14). Some curves were subjectively combined or adjusted further.
8. The new curves were then used as a base to prepare a final table of bulldozer fireline production rates classified by bulldozer sizes, fire behavior fuel models, and slope classes separated by upslope and downslope (table 4). Table 4 was prepared for bulldozers

Table 4.—Bulldozer fireline production rates (single pass) for bulldozers manufactured since 1975

Fire behavior fuel model	Slope class 1 (0%-25%) Up	Slope class 1 (0%-25%) Down	Slope class 2 (26%-40%) Up	Slope class 2 (26%-40%) Down	Slope class 3 (41%-55%) Up	Slope class 3 (41%-55%) Down
	Chains per hour					
Small bulldozers						
1, 2, 3	63	88	36	88	14	61
4	22	29	12	30	3	22
5	63	88	36	88	14	61
6	39	59	22	62	8	42
7	39	52	22	56	8	35
8	63	88	36	88	14	61
9, 11, 12	22	30	12	30	3	11
Medium bulldozers						
1, 2, 3	88	118	58	112	35	73
4	32	47	18	53	5	31
5	88	118	58	112	35	73
6	51	75	26	78	9	48
7	51	75	27	78	9	48
8	88	118	58	112	35	73
9, 11, 12	32	47	18	53	5	31
10, 13	17	23	10	25	3	11
Large bulldozers						
1, 2, 3	91	124	62	118	35	83
4	43	60	27	62	12	40
5	91	124	62	118	35	83
6, 7	63	91	41	90	22	57
8	91	124	62	118	35	83
9, 11, 12	43	60	27	62	12	40
10, 13	27	38	15	34	4	16

manufactured since 1975. Appendix A includes a similar table prepared for bulldozers manufactured from 1965 to 1975 (table 5).

Because the production rates in tables 4 and 5 were derived mathematically, there remains the task of verifying them through abbreviated field trials.

The data and procedure presented in this report were reviewed by field personnel involved in fire management. Their consensus was that our approach to adjusting older production rates to fit more modern bulldozers was reasonable. Further, the amount and direction of adjustment also appeared intuitively reasonable.

Verification from field tests and feedback from fire managers who use the new rates will lead to further adjustment of the rates, making them more accurate and more useful. The adjustments, however, cannot take into account the many small variables affecting the rate of fireline construction. Tables of production rates should not be overly refined or difficult to use.

The bulldozer fireline production rates developed in this study will probably require further adjustment and correction. Even so, they should be more useful for fire management planning than those in current fireline handbooks.

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APPENDIX A

Suggested Fireline Production Rates for Bulldozers Manufactured from 1965 to 1975

The principal objective of this study was to develop fireline production rates for newer bulldozers manufactured since 1975. In working toward that objective, however, it became apparent that there was also a need for a revised table of production rates for older bulldozers manufactured from 1965 to 1975.

The inventory of bulldozers owned or controlled by public fire protection agencies revealed that a large number of older bulldozers will continue to be used for several years. Reduced budgets are requiring State agencies, especially, to retain their bulldozers much longer than originally planned. Therefore, a revised table of fireline production rates is offered for bulldozers manufactured from 1965 to 1975 (table 5).

Table 5.—Bulldozer fireline production rates (single pass) for bulldozers manufactured from 1965-75

Fire behavior fuel model	Slope class 1 (0%-25%)		Slope class 2 (26%-40%)		Slope class 3 (41%-55%)	
	Up	Down	Up	Down	Up	Down
	Chains per hour					
Small bulldozers						
1, 2, 3	63	88	36	88	14	61
4	22	29	12	30	3	22
5	63	88	36	88	14	61
6	41	57	22	58	8	37
7	41	57	22	58	8	37
8	63	88	36	88	14	61
9, 11, 12	22	30	12	29	3	13
Medium bulldozers						
1, 2, 3	85	112	57	107	34	71
4	30	44	16	50	4	30
5	85	112	57	107	34	70
6	49	72	26	75	7	47
7	49	72	26	75	7	47
8	85	112	57	107	34	71
9, 11, 12	30	44	16	50	4	30
10, 13	17	25	11	24	3	9
Large bulldozers						
1, 2, 3	82	111	55	105	32	74
4	38	54	24	55	11	36
5	82	111	55	105	32	74
6, 7	57	82	37	80	20	51
8	82	111	55	105	32	74
9, 11, 12	38	54	24	55	11	36
10, 13	24	34	13	30	4	14

Table 5 was developed with the same procedure as that used for table 4. The only difference was in the use of production indexes from table 3 of bulldozer models manufactured from 1965 to 1975:

Small bulldozers

CDF's 1967 study

Caterpillar D4D-PS (Ser. No. prefix 22C), used in study	PI = 13
Caterpillar D4D-PS (Ser. No. prefix 83J), representative model	PI = 14
Change in PI (14–13/13)	PIΔ% = 7.7

Steele's 1954–59 study

Caterpillar D4D-DD (Ser. No. prefix 6U), observed in study	PI = 10
Caterpillar D4D-PS (Ser. No. prefix 83J), representative model	PI = 14
Change in PI (14–10/10)	PIΔ% = 40.0

Medium bulldozers

CDF's 1967 study

Caterpillar D6C-PS (Ser. No. prefix 76A), used in study	PI = 18
Caterpillar D6C-PS (Ser. No. prefix 10K), representative model	PI = 20
Change in PI (20–18/18)	PIΔ% = 11.1

Steele's 1954–59 study

Caterpillar D6C-DD (Ser. No. prefix 9U), observed in study	PI = 14
Caterpillar D6C-PS (Ser. No. prefix 10K), representative model	PI = 20
Change in PI (20–14/14)	PIΔ% = 42.9

Large bulldozers

Steele's 1954–59 study

Caterpillar D7C-DD (Ser. No. prefix 3T), observed in study	PI = 19
Caterpillar D7F-PS (Ser. No. prefix 94N), new model	PI = 25
Change in PI (25–19/19)	PIΔ% = 31.6

These production index changes produced a set of adjusted rates specifically for bulldozers manufactured from 1965 to 1975. These adjusted rates are shown in graphic form in figures 15 to 17, corresponding to figures 12 to 14 for bulldozers manufactured since 1975. The rates in table 5 were then read from figures 15 to 17.

The rates in table 5 are as tentative as those in table 4, and for the same reasons. Consequently, the production rates shown in table 5 will also be sample-tested in abbreviated field tests as opportunities arise. In keeping with the principal objective of this study, however, priority will be given to sample-testing the newer models of bulldozers.

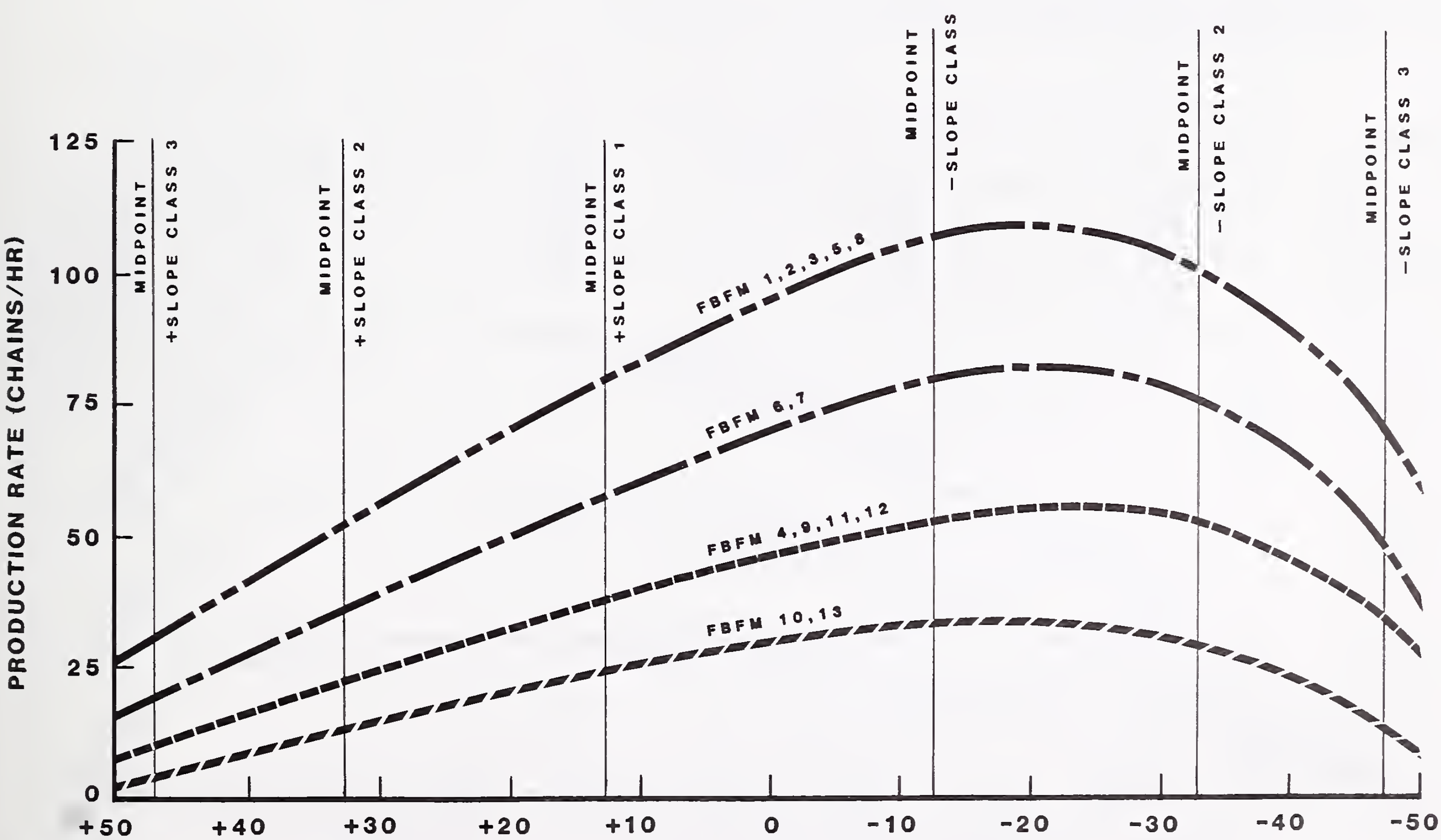

Figure 15.—Base rates for large bulldozer fireline production (single pass) adjusted to fit bulldozers manufactured from 1965 to 1975.

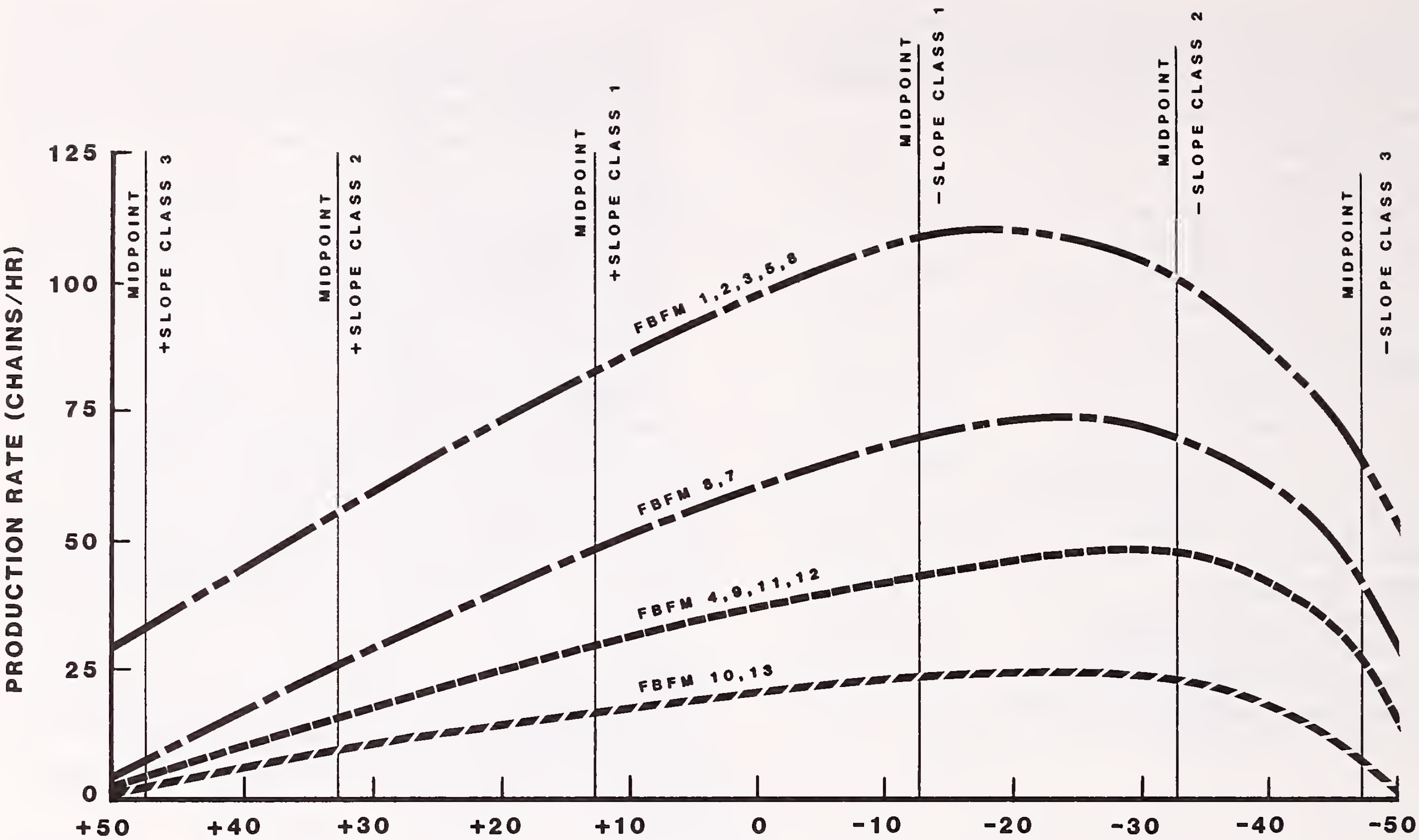

Figure 16.—Base rates for medium bulldozer fireline production (single pass) adjusted to fit bulldozers manufactured from 1965 to 1975.

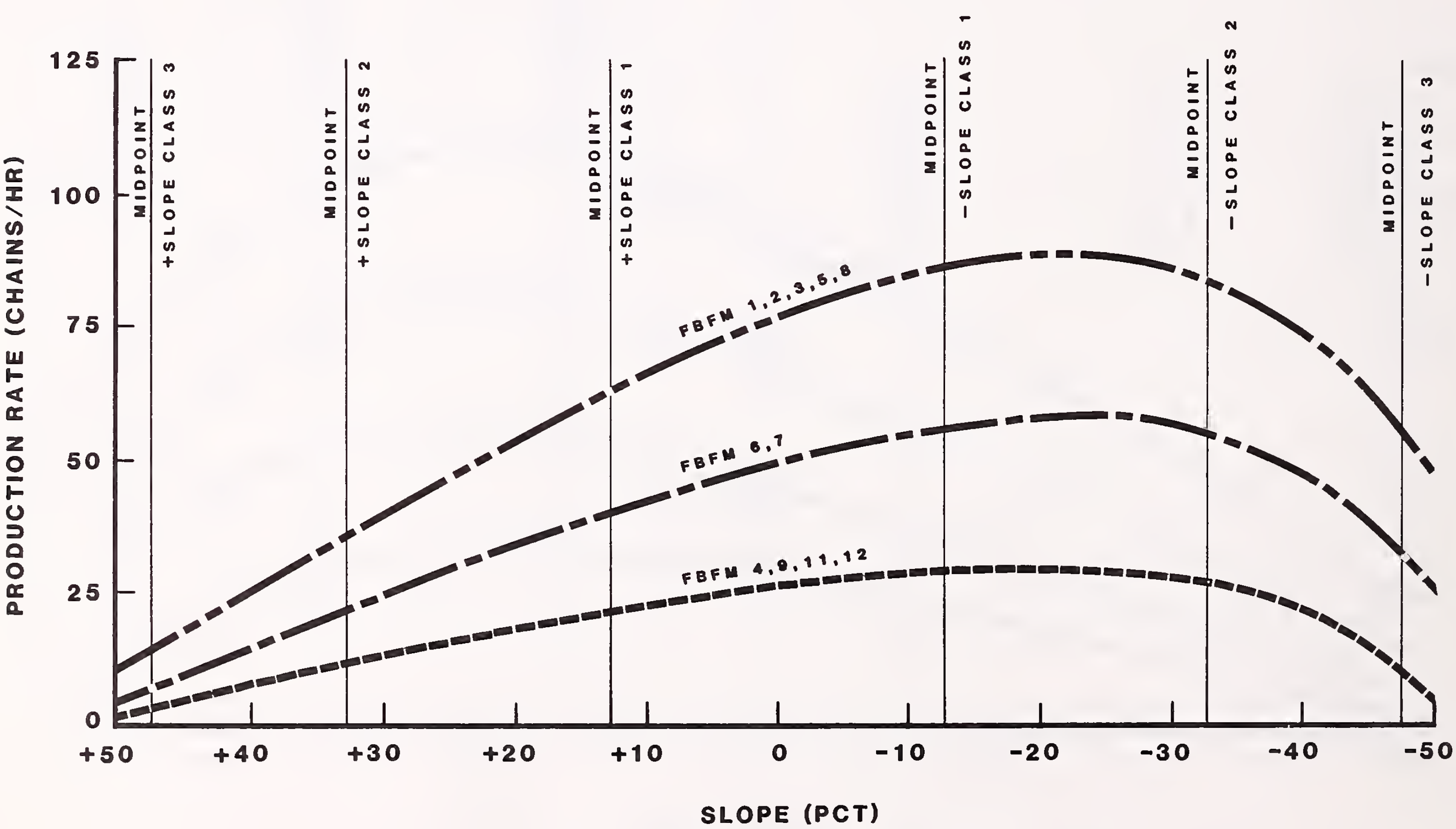

Figure 17.—Base rates for small bulldozer fireline production (single pass) adjusted to fit bulldozers manufactured from 1965 to 1975.

APPENDIX B

Relationships of Fire Behavior Fuel Models to Fuel Models of the National Fire-Danger Rating System (Anderson 1982)

NFDRS FUEL MODELS	FIRE BEHAVIOR FUEL MODELS													
	1	2	3	4	5	6	7	8	9	10	11	12	13	
A W. ANNUALS	X													GRASS
L W. PERENNIAL	X													GRASS
S TUNDRA	X					3rd			2nd					GRASS
C OPEN PINE W/GRASS		X							2nd					GRASS
T SAGEBRUSH W/GRASS		X			3rd	2nd								GRASS
N SAWGRASS			X											GRASS
B MATURE BRUSH (6FT)				X										SHRUB
O HIGH POCOSIN				X										SHRUB
F INTER. BRUSH					2nd	X								SHRUB
Q ALASKA BLACK SPRUCE						X	2nd							SHRUB
D SOUTHERN ROUGH						2nd	X							SHRUB
H SRT- NDL CLSD. NORMAL DEAD								X						TIMBER
R HRWD. LITTER (SUMMER)								X						TIMBER
U W. LONG- NDL PINE									X					TIMBER
P SOUTH, LONG- NDL PINE									X					TIMBER
E HRWD. LITTER (FALL)									X					TIMBER
G SRT- NDL CLSD. HEAVY DEAD										X				TIMBER
K LIGHT SLASH											X			SLASH
J MED. SLASH												X		SLASH
I HEAVY SLASH													X	SLASH

GRASS SHRUB TIMBER SLASH

Phillips, Clinton B.; Barney, Richard J. Updating bulldozer fireline production rates. General Technical Report INT-166. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984. 21 p.

Provides tables and performance curves for estimating rates of fireline construction for bulldozers built between 1965 and 1983. Data are derived from productivity indexes furnished by bulldozer manufacturers and have not been confirmed by field trials. Construction rates are categorized by dozer size, fuel density, and slope.

KEYWORDS: bulldozers, fireline, production, rate of construction, wildfire, tractor, tracked equipment

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)

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